

Apple Orchard Soil and Leaf Analysis

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Introduction and Literature Review

While it is commonly believed that leaf analysis is superior to soil analysis in assessing the fertility of orchard soils, few comparisons have been made of the relative ability of soil and tissue tests to distinguish good from poor trees. Only three studies have dealt with the ability of a soil test to predict the nutrient content of an apple leaf: Titus and Boynton (1953) found significant correlation coefficients of $r = 0.3$ to 0.6 between soil and leaf K, Mg, and Ca, while Wehunt and Purvis (1954) obtained a similar relationship between soil and leaf K, as well as several significant interactions. Ljones (1963) reported similar correlations for soil and leaf K, Ca, and Mg in Norwegian orchards. This suggests that while relationships do exist between the nutrient content of soil and leaf, their usefulness for prediction purposes is limited, owing to the large residual unexplained variability. Also, leaving aside the question of predicting one analysis from the other, we have no substantial reason for choosing one over the other if our goal is distinguishing well nourished prosperous trees from poorly nourished and unproductive trees.

The interpretation of a leaf analysis, once obtained, is at least as difficult as the interpretation of the corresponding soil analysis. Standard leaf composition values have been published (Kenworthy, 1961), yet reports that no adverse effects were noted in trees whose leaves contain one-half to one-third of the standard Ca concentration (Woodbridge, *et al.*, 1961) give one pause. Similarly, the observation that the concentration of leaf N was not altered by 3 years of fertilization with as much as 12 lbs. of NH_4NO_3 per tree (Weeks, 1961) is disturbing. Other complications exist: Harley, *et al.* (1958) found that early-spring growth, at least, depends on reserve nutrients stored in previous years, while Cain (1955) points out that dilution due to increased growth, as well as a changing distribution of nutrients within the plant make leaf concentration data less useful than total nutrient uptake. Finally, and perhaps most complex, are the changes in concentration of one nutrient induced by changing the concentration of another. These effects, generally referred to as interactions, have been reviewed by Emmert (1961).

The utility of either soil or leaf analysis may be questioned if the criterion of usefulness is their ability to predict the response of apple trees to fertilization. Numerous investigators have shown that, in general, nitrogen is the only fertilizer which increases yield. Boynton (1954) states that vegetative and yield responses to potassium fertilization occur, but Barden and Thompson (1962), in a study of trees whose foliar K was less than several proposed critical levels, found that 7 years of fertilization with as much as 10 lbs. of KCl per tree "resulted in neither beneficial nor harmful effects on yield or quality of the fruit." Although visual symptoms of Mg deficiency have frequently been reported, yield responses are generally not observed, and only rarely are vegetative increases noted (Forshey, 1963). According to Boynton (1954), few if any economic

responses to P fertilization have been observed, while there are no reliable reports of responses to Ca by bearing apple trees. Of the micro-nutrients, B and Zn deficiency symptoms have been reported in apple trees in the Northeast, but again, yield increases are difficult to demonstrate (Boynton, 1954).

The effect of fertilization on fruit quality, in many cases as important as quantity, is even more obscure. Again, it is generally recognized that nitrogen fertilization does affect fruit quality, abundant N usually producing fruit with less color and poorer storage qualities. Foliar K was positively correlated with storage qualities in 2 out of 4 years (Heeney and Hill, 1961), but its effect on color is questionable (Boynton, 1954). The effects of other nutrients are less clear, although B deficiency or toxicity is usually associated with poor quality and shortened storage life (Boynton, 1954). Mineral balance is also said to be important; Garman and Mathis (1956) suggesting that Baldwin spot is due to low Ca to Mg ratios.

Thus, we find ourselves in difficulty in attempting to assess the fertility of orchard soils: soil tests do not accurately predict the nutrient composition of the leaf; once obtained, leaf composition is difficult to interpret; and finally, neither the quantity nor quality of fruit is markedly affected by other than nitrogen fertilization. At this point, it is tempting to lean back on the familiar crutch that the soil-water-plant air-disease-insect system is too complex to be understood. In order to get on with the job of growing apple trees, however, we assume that a relationship does exist between the vigor of a tree, the concentration of nutrients in its leaves, and the availability of nutrients in the soil surrounding its roots. Our methods of determining these relationships are imperfect, but until new ones are devised, we report here our attempts to measure the fertility of orchard soils by soil and tissue tests.

Methods and Materials

This investigation started in 1963, when a number of growers felt that leaf analysis would aid them in determining orchard fertilizer requirements. Interested growers were provided with sampling instructions and ultimately submitted about 80 pairs of pooled soil and leaf samples. The soil samples were analyzed by our routine Morgan soil test procedures (Lunt, *et al.*, 1950); the leaves were analyzed for total N by the Kjeldahl method, and for other elements by the arc spectrograph. Linear regression analysis showed a statistically significant correlation between soil and leaf Ca, K, and N, a non-significant correlation between soil and leaf P, and no relationship between soil and leaf Mg (Table 1).

Table 1. Correlation coefficients between nutrient concentration in apple leaves and available soil nutrients of samples submitted by growers in 1963

Element in leaf	Element in soil	Correlation coefficient (r)
N	log NO ₃	0.57 **
P	P	0.20
K	log K	0.43 **
Ca	Ca	0.43 **
Mg	Mg	—

** Significant at 1% level.

The lack of correlation between soil and leaf Mg was attributed, at least in part, to a poor analytical method for soil Mg. The poor correlation for P was attributed, again in part, to the inability of most soil test methods to determine available P. Thus, although soil tests did not account for all of the observed variability in leaf nutrient concentration, these results suggested that the experiment might profitably be repeated with more attention given to improved precision in sampling and analytical techniques. Also, it was apparent that a deliberate effort should be made to collect samples from as wide a range of fertility conditions as possible: most of the samples submitted in 1963 were of relatively low fertility, a problem evident in other data (Titus and Boynton, 1953), and one which detracts from the precision of regression analysis.

To test further the hypothesis that leaf nutrient concentrations could be predicted from soil tests, approximately 100 pairs of soil and leaf samples were collected from McIntosh and Delicious orchards throughout Connecticut between July 27 and August 5, 1964. Soil and leaf samples were not pooled, as the 1963 samples had been, but each soil sample was identified with a particular tree. A subjective analysis of each tree's vigor was made according to the usual criteria (Childers, 1961) of size, number and color of leaves, length of shoot growth, and fruit set, and then each tree was classed as good, intermediate, or poor.

Soil samples were taken with a core sampler on a circle midway between the trunk and dripline to a depth of 6 inches where possible. Surface litter was discarded and at least 8 cores were then mixed, subsequently air dried, passed through a 2 mm. sieve and stored. Analyses for available nutrients were made in a 1:2 Morgan's extract, using the analytical procedures of Greweling and Peech (1960) for NO_3 , P and K, while Ca and Mg were determined by methods of Peaslee (1964, and unpublished data). Soil pH was measured in a 1:1 paste.

Approximately 50 leaves were picked from the mid-portion of the current season's terminal shoot growth, sampling each tree around its circumference at shoulder height (Emmert, 1959). The leaves were washed in a mixture of 0.1% Triton X-100 and 0.05 N HCl and rinsed with distilled water in the field. They were then dried in a forced-draft oven at 60-70° C, ground, and analyzed for total N by the Kjeldahl method, and for P, K, Ca, Mg, Mn, Fe, Al, Cu, and B by the arc spectrograph¹. Zn was not determined owing to the low sensitivity of the arc method. Methods for determining soluble or extractable nutrients were also examined: dried plant material was extracted by shaking with Morgan's solution, in comparison with the usual homogenization procedure (Boynton and Peech, 1945; Emmert, 1954; Ritter, 1954), and analyzed for NO_3 , P, K, Ca and Mg using suitable modifications of the soil analysis procedures.

Results

The average concentration of nutrients in the leaves of the three groups of trees is shown in Table 2; the available nutrients in the soil under these trees is shown in Table 3. The N content of the leaves clearly separates the trees into three groups; in all other cases neither soil nor leaf analysis could distinguish the intermediate group of trees. The results for the intermediate trees were pooled, therefore, with either the good or poor trees depending on the magnitude of the differences between the three means. A t test indicated the significance of the difference between the resulting means; the absolute value of t indicated

¹ Analyses by R. A. Botsford and W. O. Mueller are gratefully acknowledged.

Table 2. Average concentration of nutrients in the leaves of three groups of apple trees sampled in 1964, per cent of dry weight

Appearance of tree	N	P	K	Ca	Mg
Good	1.98	0.19	1.36	0.78	0.29
Intermediate	1.79	—	—	—	—
Poor	1.59*	0.24	1.32	0.71	0.25
Significance	1%	1%	n.s.	5%	1%

* Significantly different from Intermediate at 5% level.

whether soil or leaf analysis could best separate the two groups of trees. By this criterion, soil tests for K, Ca and Mg were superior to leaf analysis, while soil P was slightly inferior to leaf P in distinguishing between the good and poor trees. Also, both soil and leaf P were higher for poor than for good trees, indicating that the visual estimate of vigor was indifferent to P status. Leaf N was, of course, superior to soil N since it clearly separated all three groups of trees.

It is instructive to compare the nutrient concentration in the leaves of the good trees with the standard or critical levels suggested by others. In most cases, the concentrations are substantially less than those recommended by Kenworthy (1961); the concentration of Ca, for example, is roughly one-half of the standard 1.40%. The concentrations are also less than the proposed "critical levels" of Emmert (1955), although with the exception of Ca they are within his "desired range." Superficially, it might appear that the average "good" apple tree in Connecticut would respond to increased fertilization. Since most critical levels were obtained merely by analyzing the leaves of "good" trees, however, the utility of such levels is questionable. Furthermore, the general failure of trees to respond to other than nitrogen fertilization makes such a conclusion uncertain. Again, however, we presume that the higher fertility of the soils under the "good" trees should be maintained by continued fertilization, and that improving the fertility of the soils under the "poor" trees will produce "good" trees.

The relationships between soil and leaf nutrient content were tested further by linear regression analysis (Table 4). The results show that only leaf N and Mg are significantly correlated with their corresponding soil tests, and even for these two nutrients the fraction of the total variability accounted for is small. A plot of the relationship between soil and leaf Mg (Figure 1) shows that a wide variety of soil fertility conditions was sampled; this was generally true for the other soil nutrients as well.

Since dilution of nutrients by increased growth could explain the lack of correlation (Boynton and Compton, 1944), the total nutrient uptake, or yield,

Table 3. Average concentration of nutrients in the soil under good and poor apple trees sampled in 1964, ppm in the extract

Appearance of tree	N	P	K	Ca	Mg	pH
Good	1.56	1.35	67	285	72	5.51
Poor	1.10	1.85	48	180	38	5.18
Significance	n.s.	5%	1%	1%	1%	1%

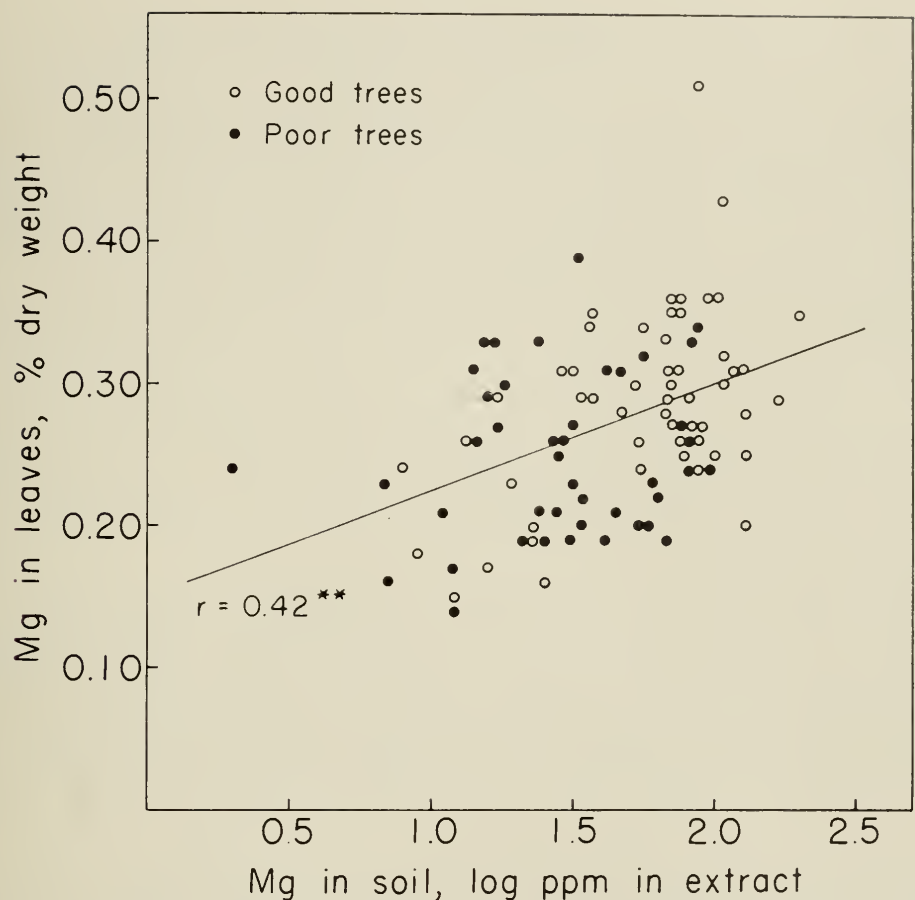


Figure 1. A plot of the relationship between soil and leaf Mg

Table 4. Correlation coefficients between nutrients in leaf (L) and soil (S), 1964 samples. Symbols of Snedecor (1946)

Variates correlated	Correlation coefficients	
	r	R
N _L vs. log N _s	0.33**	
Yield N _L vs. log N _s	0.31**	
P _L vs. P _s	0.16	
P _L vs. P _s and N _L	—	0.28*
Yield P _L vs. P _s	0.09	
K _L vs. log K _s	0.17	
Yield K _L vs. log K _s	0.34**	
Ca _L vs. log Ca _s	0.08	
Yield Ca _L vs. log Ca _s	0.25*	
Mg _L vs. log Mg _s	0.42**	
Mg _L vs. log Mg _s and N _L	—	0.55**
Yield Mg _L vs. log Mg _s	0.50**	

* Significant at 5% level.
** Significant at 1% level.

was estimated by arbitrarily multiplying the nutrient concentration by 3, 2, or 1 in the good, intermediate, or poor trees. Significant correlations were obtained between soil K or Ca and their yields in the foliage; correlations for N and Mg were unaffected, while no correlation was obtained between yield of P and soil P. Multiple regression analysis showed that leaf N markedly depressed leaf P and increased leaf Mg, so that significant, although not very useful, correlations were demonstrated for all five nutrients (Table 4). It should be noted that since soil nutrient concentrations were different and leaf concentrations were either equal or slightly different for the three classes of trees, the weighting of leaf concentrations was bound to improve or even create a significant relation.

Since the literature suggests that many ion interactions are important, a number of the more logical ones were tested. Although high K has frequently been reported to depress leaf Mg (Boynton and Burrell, 1944; Emmert, 1961; Wehunt and Purvis, 1954), multiple regression analysis of yield Mg as a function of soil Mg and K rather than soil K alone gave no significant improvement in prediction of leaf Mg.

High N has been reported (Boynton and Compton, 1944) to decrease leaf P and K and increase leaf Mg and Ca. Of these effects, only the increase in leaf Mg and decrease in leaf P were found (Table 4) to be significant. Otherwise, no improvement in prediction of yield of Mg, K, or Ca was obtained by including other soil cations in the regression analysis. This may be due in part to use of nutrient yield, which suggests that some reported interactions may be due to dilution.

One further possible explanation for the observed variability in leaf nutrient concentration was examined. Since a deficiency in one nutrient may inhibit growth while other elements accumulate, leaf Ca concentrations were adjusted downward whenever the leaf concentration of another element fell more than 15 per cent below the grand mean for all trees. When more than one element was low, the lowest was used, and the Ca concentration was reduced by the appropriate percentage. Regression analysis of these adjusted Ca concentrations as a function of log Ca in the soil gave $r = 0.18$, more than double the original (0.08, Table 4), and significant at the 10% level, indicating that the adjustment probably makes sense, but again it is of little utility.

The comparisons between the tests for soluble and total nutrients in apple leaves may be summarized as follows: Most of the total K and from 50 to 80 per cent of the total P can be extracted by shaking the dried tissue with Morgan's solution. Correlation coefficients of $r = 0.80$ for K and 0.86 for P indicate a less precise relationship than that found for K by Boynton and Peech (1945) or for K and P by Ritter (1954). Only small amounts of Ca (about 10% of the total) were extracted by this technique, and in the few samples tested there appeared to be little or no correlation between soluble and total Ca. Although Emmert (1954) was able to extract reasonable amounts of Ca by homogenization of fresh tissues, neither his results nor those of Ritter (1954) indicate a very precise correlation between the two tests. Analysis of a limited number of samples showed that most of the Mg could be extracted by shaking with Morgan's solution, consistent with the findings of Boynton and Peech (1945) using homogenized tissues. Only small amounts of NO_3 were found in homogenized fresh leaves (Emmert, 1954), and virtually none was present in the extract of our dried leaves.

Discussion and Conclusions

The objectives of this study were twofold: to determine the relative ability of soil and tissue tests to distinguish good from poor trees, and to determine what correlation exists between the two tests. We may dispose of the latter readily, since our results and those of others show that available soil nutrients measured by our present soil tests are not well correlated with nutrient concentrations in the leaves. Dilution of nutrients by growth, enhanced concentration owing to deficiencies in other nutrients, and ion interactions are explanations frequently offered and evident to greater or lesser extent in our own data. While these "explanations" are comforting, they are in fact symptoms that our knowledge of inorganic plant nutrition is far from complete. This is hardly a novel conclusion; neither is it useful unless it generates some useful experimentation.

Recently, Platt (1964) has presented a stimulating analysis of why some fields of science are moving ahead more rapidly than others. To use some of his expressions, let us, for example, discard the "single Ruling Theory" that leaf analysis is superior to soil analysis (or vice versa) and adopt instead multiple working hypotheses. Let us avoid "The Frozen Method" and look for new soil test techniques. "The Eternal Surveyor . . . substituting correlations for causal studies" does not move ahead a great deal either². Finally, "The All-Encompassing Theory Which Can Never Be Falsified," such as the prediction that leaf N is high when soil N is high, except when it is low because of secondary effects, is not much use.

To return to the business of growing apple trees, it is clear that our present soil tests did a better job of distinguishing good from poor apple trees than did leaf analyses for K, Ca, and Mg. Leaf P was slightly superior to soil P in distinguishing the two groups, although both were lower for the good than poor trees. Leaf N divided the trees into three groups, good, intermediate, and poor, but this separation was evident to the eye. Although Childers (1961) feels that leaf analysis is more useful than soil analysis, his statement that "insofar as fruit crops are concerned, about the only value of soil analysis is to indicate the pH and whether the potash, magnesium and phosphorous (and boron when analyzed) are excessively high or low" seems a fair summary of our findings.

Thus, a soil test will distinguish between the pH, P, K, Ca, and Mg content of good and poor orchard soils, and a simple visual observation will give an estimate of the N content of the foliage. Having failed to establish the superiority of the more elaborate tissue test, it appears that a quick, simple, inexpensive soil test is the more logical choice.

² As may be judged from the present contribution.

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